# FINAL TECHNICAL REPORT

***Bayesian Methods for Radiation Detection and Dosimetry***

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## Executive Summary:

We performed work in three areas: **radiation detection, external and internal radiation dosimetry.**

In **radiation detection** we developed Bayesian techniques to estimate the net activity of high and low activity radioactive samples. These techniques have the advantage that the remaining uncertainty about the net activity is described by probability densities. Graphs of the densities show the uncertainty in pictorial form. Figure 1 below demonstrates this point. We applied stochastic processes for a method to obtain Bayesian estimates of $^{222}$Rn-daughter products from observed counting rates.

In **external radiation dosimetry** we studied and developed Bayesian methods to estimate radiation doses to an individual with radiation induced chromosome aberrations. We analyzed chromosome aberrations after exposure to gammas and neutrons and developed a method for dose-estimation after criticality accidents.

The research in **internal radiation dosimetry** focused on parameter estimation for compartmental models from observed compartmental activities. From the estimated probability densities of the model parameters we were able to derive the densities for compartmental activities for a two compartment catenary model at different times. We also calculated the average activities and their standard deviation for a simple two compartment model.

In **summary** the results in **radiation detection** are useful for the analysis of counting experiments in the presence of background and could be applied, for example, in the evaluations

of occupational bioassay results in volving uranium and other internally deposited radionuclides. The techniques for $^{222}$Rn daughter detection could be used for the design of a sophisticated instrument to measure low daughter concentrations irregardless of the existing equilibrium. Our findings in biological **external radiation dosimetry** provide new methods for dose estimation in different radiation emergencies in volving neutron and gamma radiation or mixtures of the two radiation types in criticality accidents. The procedures for parameter estimation and prediction of compartmental activities will be useful in **internal radiation dosimetry** in occupational monitoring and nuclear medicine.

The analysis of multi-channel spectroscopy data was **not** completed, as originally planned, because of mathematical problems stemming with the multinomial distribution.

One Ph.D. student was supported under this contract. He completed a doctoral dissertation (see below) and received a Ph.D. in Nuclear Engineering in May, 2002.

A summary of papers and presentations is given below.

**Summary of Publications and Presentations :**

**Papers submitted and to be published in journals:**

1) Brame, S., Groer, P.G., Bayesian Estimation of Neutron Doses Using Chromosome Aberrations and Ancillary Prior Information, *Transactions of the American Nuclear Society*, 82, 118-120, 2000.

2) Groer, P.G., Brame, S., Bayesian Methods for Radiation Dosimetry, *Transactions of the American Nuclear Society*, 84, 110-111, 2001.

3) Groer, P.G., Brame, S., Biological Dosimetry with Uncertain Calibration Doses, *Transactions of the American Nuclear Society*, 86, 171-172, 2002.

4) Groer, P.G., Exact and Approximate Bayesian Estimation of Net Counting Rates, (accepted and to be published in *Radiation Protection Dosimetry*)

5) Brame, R.S., Bayesian Analysis of Overdispersed Chromosome Aberration Data with the Negative Binomial Model, (accepted and to be published in *Radiation Protection Dosimetry*).

6) Lo,Y., Groer, P.G., Bayesian Estimation of Calcium Exchange Rates at Bone Surfaces in Beagles (submitted to *Health Physics*, under revision).

7) Brame, R.S., Groer, P.G., Bayesian Methods for Chromosome Dosimetry Following a Criticality Accident (submitted to *Radiation Protection Dosimetrys*, under revision).

8) Brame, R.S., Groer, P.G., Bayesian Approach to Chromosome Dosimetry with Uncertain Calibration Doses (submitted to *Technometrics*)

A **doctoral dissertation** describing applications of Bayesian methods to external and internal radiation dosimetry was completed and defended by Dr. Scott Brame in May 2002.

**Presentations at Meetings:**

1) Brame, S., Groer, P.G., Bayesian Estimation of Neutron Doses Using Chromosome Aberrations and Ancillary Prior Information, *Annual Meeting of the American Nuclear Society*, San Diego, 2000.

2) Groer, P.G., Brame, S., Chromosome Dosimetry after Accidental Exposure to Radiation, *International Society of Bayesian Analysis*, $6^{th}$ World Meeting, Heraklion, Crete, 2000.

3) Groer, P.G., Brame, S., Bayesian Methods for Radiation Dosimetry, *Summer Meeting of the American Nuclear Society*, Milwaukee, 2001.

4) Groer, P.G., Lo,Y., Bayesian Estimation for Immigration Death-Processes Applied to Radiation-Detection, $2^{nd}$ International Workshop on Bayesian Inference in Stochastic Processes, Varenna, Italy, 2001.

5) Groer, P.G., Brame, S., Bayesian Approach to Compartmental Modeling with Missing Observations, *C. Warren Neel Conference on Statistical Data Mining*, Knoxville, Tennessee, 2002

6) Brame, S., Groer, P.G., Compartmental Modeling of $^{45}Ca$ Biokinetics with Missing Observations, *$7^{th}$International Radiopharmaceutical Symposium,* Nashville, Tennessee, 2002

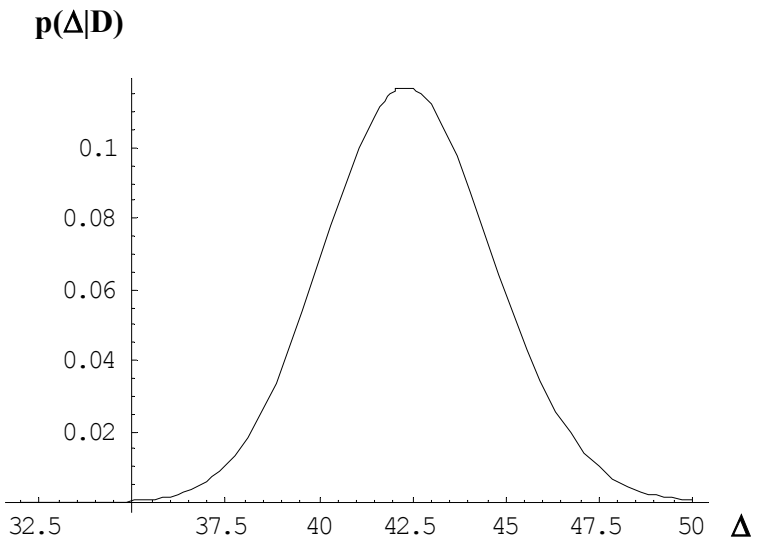
**Presentations at Meetings (continued):**

7) Groer, P.G., Brame, S., Bayesian Significance Tests for Overdispersion, *7th Valencia International Meeting on Bayesian Statistics,* Tenerife, Spain, 2002.

**Research Areas:**

**Radiation detection:**

We derived posterior densities for the net counting rate in the presence of background for the single channel case. We used a Poisson model for low count rate data and the Normal approximation to the Poisson for large counting rates. Shown below, for example, is the graph of the posterior density for the net counting rate Δ for 7.7 background counts/minute counts and 50 sample counts/minute using a Poisson model.



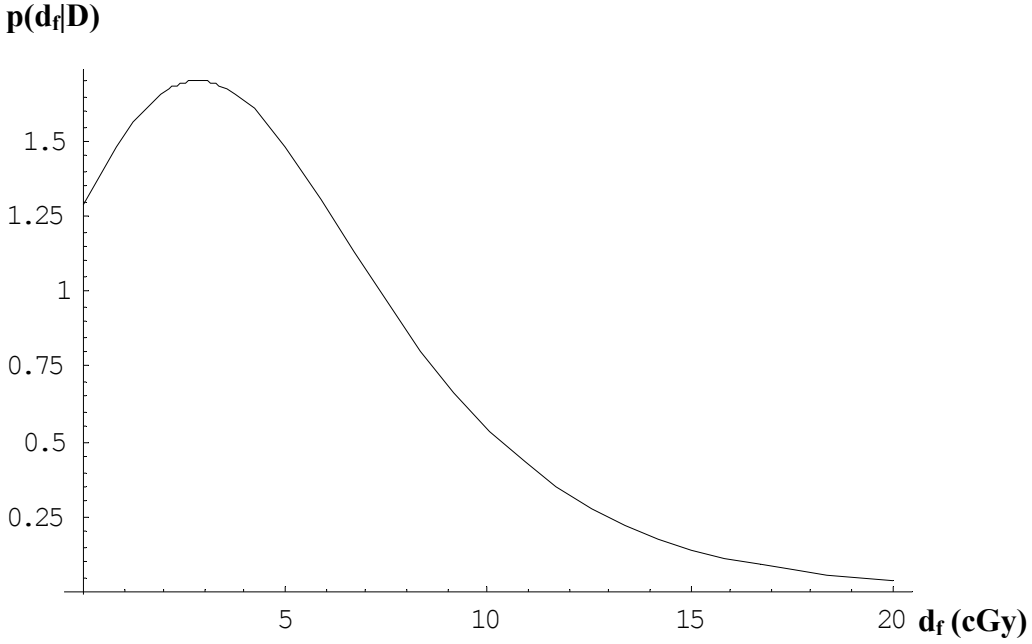

We completed work on comparison of exact and approximate methods to estimate net-counting rates. A paper describing our findings has been accepted for publication by *Radiation Protection Dosimetry.*

We applied so called immigration-death processes to the problem of $^{222}$Rn-daughter detection. The immigration rate describes the arrival rate of radioactive nuclei on filter paper as air is drawn through the filter by a pump set to a constant flow rate. The "death

rate" is the rate of decay of the radionuclides. We presented a summary of this work at 2nd International Workshop on Bayesian Inference in Stochastic Processes in Varenna, Italy (see above).

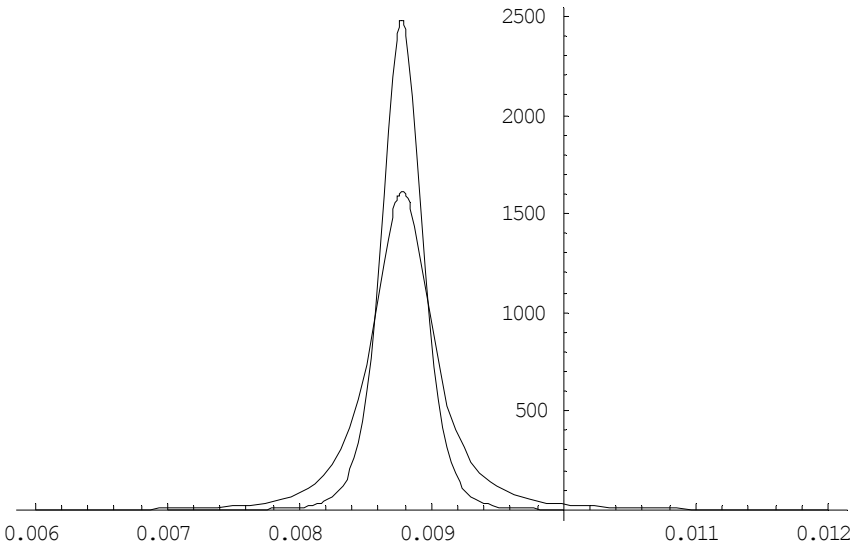
**External Radiation Dosimetry**

In biological dosimetry we derived calibrative densities of the unknown accident dose for linear and linear-quadratic models. The linear dose-response model is the "public" model for the production of dicentric chromosome aberrations after exposure to neutrons and the linear-quadratic model is the accepted model for exposure to low LET radiation. The calibrative density describes the remaining uncertainty about the unknown accidental dose. An example of a calibrative density for the unknown neutron dose $D_f$ is shown below.



We completed analyses of data on chromosome aberrations induced by neutrons using a Polya model to study over dispersion. Over dispersion means that the variance is greater than the mean of the distribution. Equality of these quantitities characterizes the Poisson model. A paper describing our results will be published in *Radiation Protection Dosimetry* (see above).

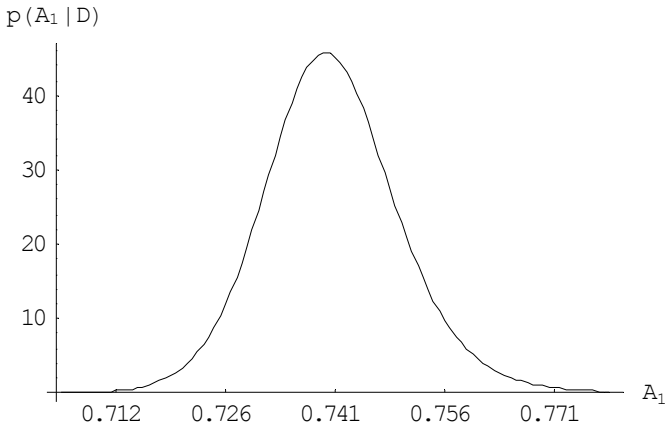
We also completed work on parameter estimation and the calibration problem for the case of imprecise doses in the calibration experiment. The difference in the slope estimates for a linear model is shown below. The more peaked curve represents the estimated slope for precise doses in the calibration experiment. A paper describing these results was submitted to *Technometrics* for review.




Work on neutron and gamma dose estimation after a criticality accident was also completed and a manuscript was submitted to *Radiation Protection Dosimetry* for review.

**Internal Radiation Dosimetry**

In internal dosimetry it is of interest to see how compartmental activity and the uncertainty about it change as a function of time. With the Bayesian approach we derived the density functions for compartmental activities for a two compartment catenary model by transformation of the joint density of the model parameters. The figure on the next page shows the activity $A_1(5)$of the first compartment at t=5. This is the first derivation of a time dependent density for activity in internal dosimetry. We also analyzed some compartmental data relevant for Boron Neutron Capture Therapy with our techniques. We experimented with lattice integration methods for multidimensional numerical integration for compartmental analysis with missing compartmental activities.




A summary of our work on the influence of missing observations on the estimation of transfer coefficients was presented at the 7th International Radiopharmaceutical Symposium (see above). Interest in application of our methods to a similar compartmental model led to cooperation with the University of Pisa, Italy.